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RESEARCH MEMORANDUM

SLOWING-DOWN DISTRIBUTION TO INDIUM RESONANCE OF NEUTRONS FROM A Ra-α-Be SOURCE IN WATER-IRON MIXTURES

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SLOWING-DOWN DISTRIBUTION TO INDIUM RESONANCE OF NEUTRONS FROM A Ra-α-Be SOURCE IN WATER-IRON MIXTURES

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SUMMARY

The mean square slowing-down distance to indium resonance $\overline{r^2}$ derived from the slowing-down distribution has been measured for water and for three water-iron mixtures for neutrons from a 0.1-gram Ra-α-Be source. The values of $\overline{r^2}$ for water-iron volume ratios of 1, 2, and 3 and for water were 347, 336, 314, and 291 centimeters squared, respectively. Within the accuracy of the measurements, the relaxation length λ was approximately the same for water and for the three water-iron mixtures, the average value being 10.0 centimeters.

INTRODUCTION

The distance traveled by fast neutrons in a chain reacting system during moderation is important to reactor criticality requirements. In recent years many measurements have been made of the mean square slowing-down distance in various media using fission, photoneutron, and Ra-α-Be neutron sources (refs. 1 to 7). In the design of power reactors iron is used in considerable quantities as a structural material and its effect on criticality is very important in that the addition of iron to water may decrease the efficiency of the slowing-down process.

Measurement of the mean square slowing-down distance of neutrons to indium resonance for water-iron mixtures provides quantitative indications of the moderating properties of these mixtures. In reference 2, the mean square slowing-down distance to indium resonance was measured in a water-iron volume mixture of 1.3 using a checkerboard lattice of iron rods and a 1-gram Ra-α-Be neutron source, and also in water-bismuth and water-lead mixtures. In the present work, similar measurements were made for three water-iron mixtures (3, 2, and 1 by volume) using a 0.1-gram Ra-α-Be fast neutron source to determine the effect of iron on the moderating properties of the mixtures. In this work the iron was placed in the water in the form of thin slabs.

EXPERIMENTAL ARRANGEMENT AND MEASUREMENT PROCEDURE

The volume ratios of iron to water required for this work necessitated the use of iron in bulk form. It was decided to use the iron as plates stacked on iron racks so that volume ratios of water to iron could be easily measured and still approximate a homogeneous mixture. The iron used was of low carbon content specified as in the range SAE 1010 to 1020.

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The iron consisted of plates 3 by 15 by 1/16 inch separated by washers cut from randomly selected plates. The average thickness of a washer was 0.0625±0.002 inch, and these washers controlled the spacing of the plates to produce the desired water-to-iron volume ratio. The distribution of iron plates in water closely approximates homogeneous mixtures of water and iron, since the distance between the plates of each mixture is considerably less than the scattering mean free path for that mixture for the peak energies of the Ra-α-Be neutron spectrum of 5 Mev and 200 kev.

A photograph of the 1-to-1 by volume water-to-iron assembly is shown in figure 1. The iron plates were strung on five separate racks which were in turn bolted together. Usually 20 of the plates in the middle rack were fitted with sliders to hold the cadmium-covered indium foils. The iron tube in the middle rack held the neutron source. Within the tube and above the source was placed a polyethylene-iron assembly to simulate the particular water-iron mixture under test. The source was located 7.5 inches from either side of the rack, 7 inches from one end, and 7.5 inches from the bottom; the distance along the axis of measurement was 29 inches. Since the dimensions of the assembly are greater than the values of $\sqrt{\overline{r^2}}$ measured, the fluxes are expected to be approximately spherically symmetric around the source and to be relatively unaffected by the boundaries along the axis of measurement.

The water-iron assemblies measured 15 by 15 by 36 inches and were placed in a 2 by 2 by 4 foot iron tank filled with water so as to give a minimum of 4 inches of water between the tank and the assembly.

Corrosion was controlled by (1) coating the plates with a very thin layer of ferric oxide, (2) adding an inhibitor to the water - this consisted of 1 part sodium chromate added to every 2000 parts H_2O with the pH of the solution raised to about 8 by the addition of sodium hydroxide, (3) mechanically filtering the water by pumping through a closed system at the rate of about 1 gallon per minute.

The distances from the center of the source to a foil were measured by a cathetometer and were reproducible to 0.01 centimeter. The activity of indium foils was measured by a Geiger-Mueller tube having a thin mica window and connected to a decimal scaler. The G-M tube had a background count of about 10 to 13 counts per minute. Before each run the scaler was checked for consistency by means of a Bi^{210} source having a half-life of 22 years.

The indium resonance neutron flux was measured from 2.5 to about 34 centimeters from the source for all three water-iron mixtures. In order to obtain higher counting rates at large distances from the source, three sizes of indium foils were used for the measurements: (a) foils 1 by 1 centimeter and weighing approximately 0.6 gram per square centimeter in the region from 2.5 to 15 centimeters, (b) foils 2.54 centimeters in diameter and of weight 0.17 gram per square centimeter in the region from 10 to 25 centimeters, (c) foils 2.54 by 2.54 centimeters and weighing approximately 0.17 gram per square centimeter from 12 to 34 centimeters. For water, an additional set of measurements was made using the foils described in (b) from 2.5 to 25 centimeters. The indium foils described in (a) and (b) were covered with 40-mil cadmium and measured the indium resonance neutron distribution from 2.5 to 25 centimeters. The foils described in (c) were needed to measure the total neutron flux distribution and were covered with aluminum. At relatively large distances from the source, the ratio of the total neutron flux to the indium resonance flux (the cadmium ratio) should be nearly constant (p. 18, ref. 7). With this constant value of cadmium ratio, the indium resonance neutron flux distribution can be extended from 25 to 34 centimeters. The three sets of indium foils were calibrated with respect to one member of each group. Inasmuch as the saturation activity of the side of the foil facing the source was measured, it may contain a current component due to streaming from the source (p. 11, ref. 1). In one of the two sets of data for water, measurements were made to determine whether the forward component of the flux as indicated by the activity of the front face of an irradiated indium foil was satisfactory for evaluating the mean square neutron slowing-down distance to indium resonance $\overline{r^2}$. As will be shown, values of $\overline{r^2}$ computed using front saturation activity agreed closely with values of $\overline{r^2}$ obtained using measured neutron flux distributions as indicated by the sum of the front and back saturation activities for water.

The fast neutron source was a Ra-α-Be type consisting of 0.1-gram of radium sulfate powder mixed with beryllium powder. A monel metal cylinder enclosed the powdered mixture which was pressed into pellet form. The outer dimensions of the source were 0.43 inch diameter and 0.51 inch length. The Ra-α-Be source is a polyenergetic fast neutron source having energies from 13 Mev on down. About 75 percent of the neutrons are in a region with a peak energy of about 5 Mev, and about 25 percent of the neutrons are in a region with a peak energy of 200 kev (p. XV, ref. 3). A spectrum of a Ra-α-Be source is given on page 11 of reference 3.

CALCULATIONS AND EXPERIMENTAL RESULTS

The saturation activity of an indium foil A_s, measured in counts per minute, was obtained by exposing the foil to neutrons at a distance r from the source. The decay constant used in calculating A_s was 0.01284 per minute. The quantity A_s is directly proportional to the flux of indium resonance neutrons when obtained by indium foils covered with cadmium. The number of resonance neutrons found in a shell of thickness dr and mean radius r is therefore given by $4\pi A_s r^2 dr$ if the system is spherically symmetric. The mean square slowing-down distance for fast neutrons from a point source to indium resonance is then given by

$$\overline{r^2} = \frac{4\pi \int_0^\infty A_s r^4 dr}{4\pi \int_0^\infty A_s r^2 dr} \tag{1}$$

The characteristic slowing-down length L_s is defined by

$$L_s^{\,2} = \frac{1}{6}\,\overline{r^2} \tag{2}$$

The quantity $A_s r^2$ for indium resonance neutrons is plotted against r on a semilog scale in figure 2 for water and the three mixtures of water and iron. The number of indium resonance neutrons to be found at a given distance from the source increases with increasing iron content.

In figure 3 is presented a plot of the saturation activity due to the total neutron flux A_s against foil position r for water and the three water-iron mixtures. The curves for the three water-iron mixtures differ only slightly; however, the curve for water has a higher saturation activity by a factor close to 3. Evidently the absorptive properties of the iron tend greatly to depress the thermal flux. Since the ratio of saturation activity due to the total neutron flux to the activity due to the indium resonance flux, the cadmium ratio, was nearly constant from about 12 to 25 centimeters for the water-iron mixtures and water, the data plotted in figure 3 were used to extend the cadmium-covered activations from about 25 to 34 centimeters.

The values of $\overline{r^2}$ for the various water-iron mixtures and for water were computed from the experimental data using equation (1). The integrals were evaluated as follows: The infinite interval of integration was divided into three parts. The first interval was 0 to 4 centimeters. In this interval, parabolas were fitted to the experimental values of $A_s r^2$ and $A_s r^4$ for three values of r and the resulting

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functions of r were used for $A_s r^4$ and $A_s r^2$, the integrands of the integrals in the numerator and denominator, respectively. The second interval ranged from 4 to 32, 34, 30, and 32 centimeters for water and the 3, 2, and 1 volume ratio water-iron mixtures, respectively. In this interval the integrations were performed numerically using Simpson's rule. The third intervals began with the terminal points of the second intervals and extended to infinity. Here the integrations were performed using the assumption

$$A_s = \frac{Ke^{-r/\lambda}}{r^2} \tag{3}$$

which is a good approximation at large distances from a point source. In equation (3), λ is the relaxation length of indium resonance neutrons and K is a constant of proportionality. For each of the water-iron mixtures and for water, a λ was computed from the data near the largest r's in the measurements shown in figure 2. All these values fell within a narrow range, so the average value of 10.0 centimeters was used in all the computations. The constant K was determined for each mixture at the corresponding end points of the second intervals.

Table I lists all pertinent information derived from the measurements. Approximately 12 to 15 percent of the $\int_0^\infty A_s r^2 dr$ and from 35 to 46 percent of the $\int_0^\infty A_s r^4 dr$ were extrapolated for the various mixtures considered. The computed values of the mean square slowing-down distance $\overline{r^2}$ for the three water-iron mixtures (3, 2, and 1) were 314, 336, and 347 centimeters squared, respectively, and the value was 291 for water. The additional set of measurements for water using foils weighing 0.17 gram per square centimeter in the entire range of measurements provided a value $\overline{r^2}$ of 302 centimeters squared. (This set of data is used later to evaluate the current component of the flux streaming from the source.)

The variation of $L_s^2 = \overline{r^2}/6$ with iron concentration is shown in figure 4. The two values obtained for water are shown. The figure indicates that as water is replaced by iron the effectiveness of the mixture in slowing down Ra-α-Be neutrons is not greatly decreased as a result of inelastic and elastic scattering by the iron nuclei. The experimental scatter of the data points from the faired curve is ±3 percent. Two values of L_s^2 obtained in reference 2 are included in figure 4 for comparative purposes; these values are slightly lower than those of the present work. (Munn and Pontecorvo used a 1-gm Ra-α-Be neutron source and assembled the water-iron mixture by placing square iron rods, 32 by 1.87 by 1.87 cm, in a checkerboard pattern throughout a tank of water.)

PRECISION OF MEASUREMENTS

The measurement of the indium resonance neutron distribution in water, counting only the front face of the indium foil, may be compared with other experimental results. This comparison serves as a basis for evaluating the accuracy of the present water-iron measurements. The present data derived from the water measurements are included in table II, which is reproduced from page 107 of reference 3. The present data agree well with the results of other experiments.

The source used was assumed to be effectively a point source and epiresonance activations in indium were neglected. Corrections for source size were found to be negligible for distances greater than a few centimeters from the source; corrections for epiresonance activations were found to be small and to apply only to a region near the source (refs. 4 and 7), which contributes only a small part to the values of $\overline{r^2}$.

A more important source of error in evaluating $\overline{r^2}$ is in the value of λ, which was estimated from the data farthest from the source where counting statistics are poorest. A check of table II shows that the experimental value of 10.0 centimeters of the present work agrees with other experimental measurements.

The large thickness of foils used in the region from 2.5 to 15 centimeters from the source tends to depress the flux surrounding the foil and may introduce a possible error. Again, since the region near the source contributes a relatively small part to $\overline{r^2}$, these possible errors are minimized.

As previously mentioned, counting only the front face of the foils may introduce an error because of the presence of a current component streaming from the source. This effect has been evaluated as follows: With thin foils weighing 0.17 gram per square centimeter and 2.54 centimeters in diameter, measurements were made in water of the mean square slowing-down distance to indium resonance using three methods of interpreting the saturated foil activities. In the first case, only the front face of the foil was counted; in the second case, only the back face of the foil; and in the third case, the sum of the counts from the front and back of the indium foils was used. In figure 5 is presented a plot of the ratio of the counts per minute of the front face of the foils A_s to the counts per minute of the back face A_s'

as a function of r. It is evident from the figure that there is a current component of the neutron flux which is strongest at about 9 centimeters from the source. In figure 6 is shown a plot of $A_s r^2$ at each position r for the three methods of interpreting the saturated foil activities. The values of $\overline{r^2}$ for the three cases cited were 302, 309, and 304 centimeters squared for the front face counts, back face counts, and sum of counts on front and back, respectively. The front face activations therefore lead to values of $\overline{r^2}$ which very closely agree with values of $\overline{r^2}$ obtained using front plus back activations. For mixtures of water and iron this error is even less than in water, since the flux will have a smaller current component because of the presence of heavy iron nuclei. This was confirmed by a few measurements of A_s/A_s' for the three water-iron mixtures. In each case, additional iron in the system reduced the streaming effect as indicated by the smaller variation of A_s/A_s' with r.

Comparison of the two independent sets of measurements for water in the region 2.5 to 25 centimeters from the source resulted in values of $\overline{r^2}$ of 291 and 302 centimeters squared. This difference serves to indicate the order of reproducibility.

SUMMARY OF RESULTS AND CONCLUSIONS

The mean square slowing-down distance to indium resonance $\overline{r^2}$ was measured for three water-iron mixtures and for water. The values of $\overline{r^2}$ for water-iron volume ratios of 1, 2, and 3 and for water were 347, 336, 314, and 291 centimeters squared, respectively. Within the accuracy of the measurements, the relaxation length λ was approximately the same for water and for the three water-iron mixtures, the average value being 10.0 centimeters. The use of front face activations of indium foils appears to be a good measure of the neutron flux for mixtures considered insofar as evaluation of $\overline{r^2}$ is concerned.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, August 10, 1954

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7. Hill, J. E., Roberts, L. D., and Fitch, T. E.: The Slowing Down Distribution from a Point Source of Fission Neutrons in Light Water. AECD 3392, Oak Ridge Nat. Lab., Carbide and Carbon Chem. Corp., Dec. 10, 1948.

TABLE I. - RELATIVE VALUE OF INTEGRALS AND PERTINENT INFORMATION DERIVED FROM MEASUREMENTS FOR WATER AND WATER-IRON MIXTURES

Mixture	$\int_0^\infty A_s r^2 dr$	$\int_0^\infty A_s r^4 dr$	λ, cm	Mean square slowing-down distance to indium resonance, $\overline{r^2}$, cm^2	Characteristic length to indium resonance, L_s^2, cm^2
H_2O	1.276×10^5	3.708×10^7	10.0	291	48.5
H_2O	5.418	16.34	10.0	302	50.3
$3H_2O:1Fe$	1.618	5.075	10.0	314	52.3
$2H_2O:1Fe$	1.791	6.017	10.0	336	56.0
$1H_2O:1Fe$	2.155	7.474	10.0	347	57.9

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TABLE II. - TABULATION OF H_2O MEASUREMENTS FROM PAGE 107

OF REFERENCE 3 AND PRESENT WORK

Investigator	Ra-α-Be source strength, g	Indium resonance, $\overline{r^2}$, cm^2	Indium resonance, L_s^2, cm^2	Relaxation length, λ, cm
Dacey, Paine, and Goodman	1.03	313	52.2	9.8
Munn and Pontecorvo	1.0	278	46.4	10.1
Amaldi and Fermi	(a)	277	46.2	9.4
Tittle	0.12	288	48.0	9.4
Rush	(a)	272	45.4	9.38
Present work	0.1	291	48.5	10.0
	.1	302	50.3	10.0

[a]Not given in reference 3.

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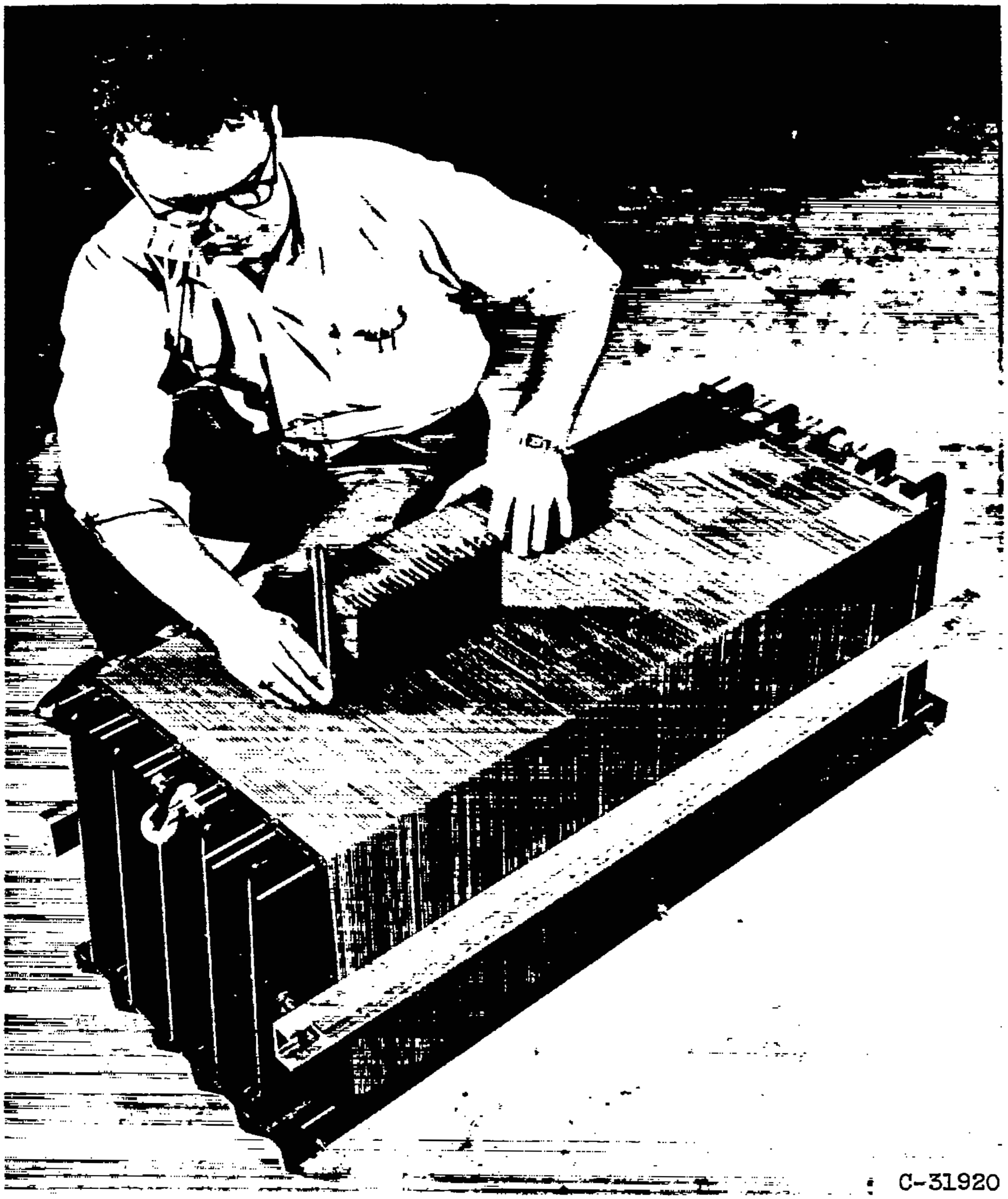

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Figure 1. - The 1-to-1 volume ratio water-iron assembly.

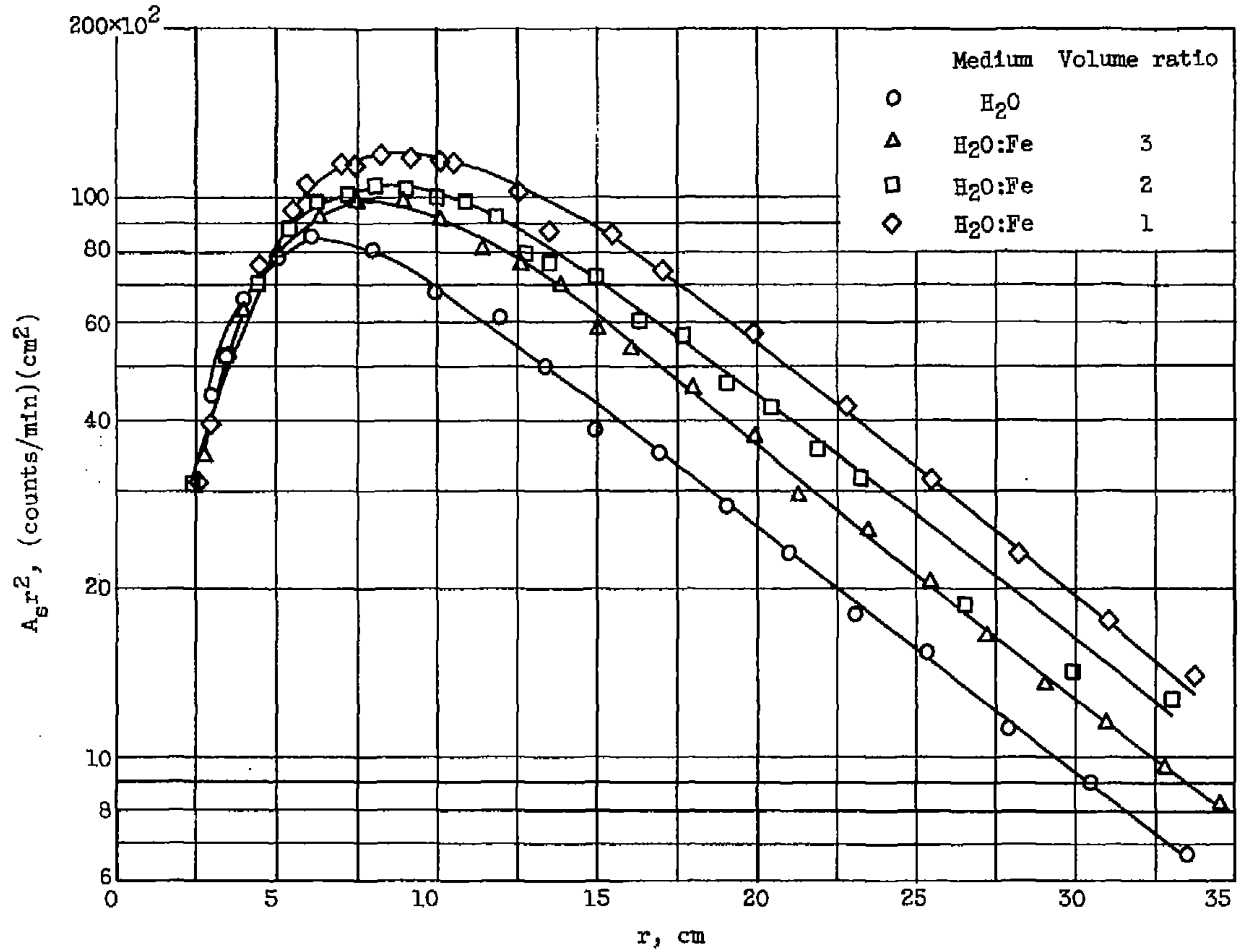

Figure 2. - Indium resonance neutron distributions.

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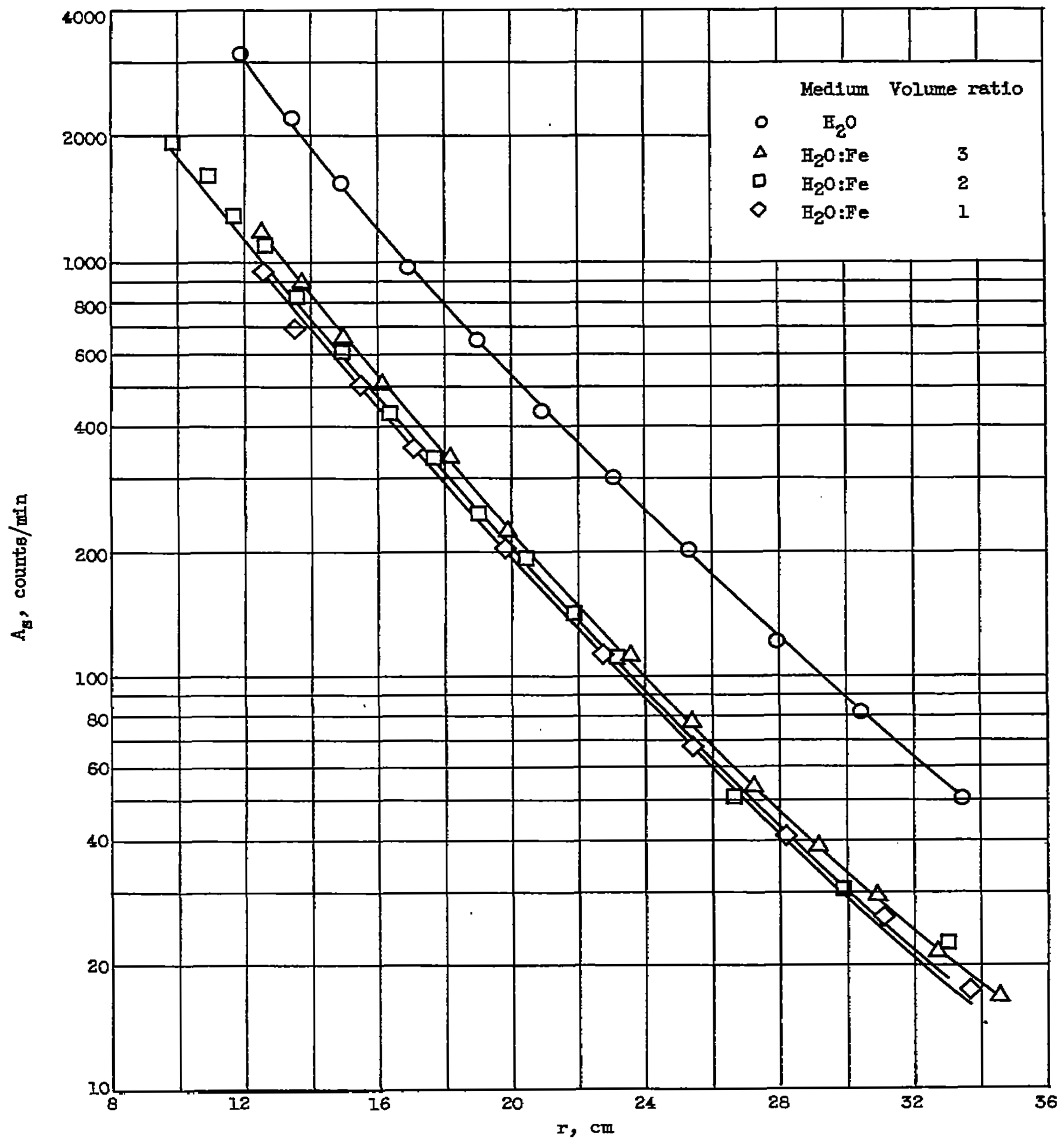

Figure 3. - Saturation activity in counts per minute due to fast and thermal neutrons.

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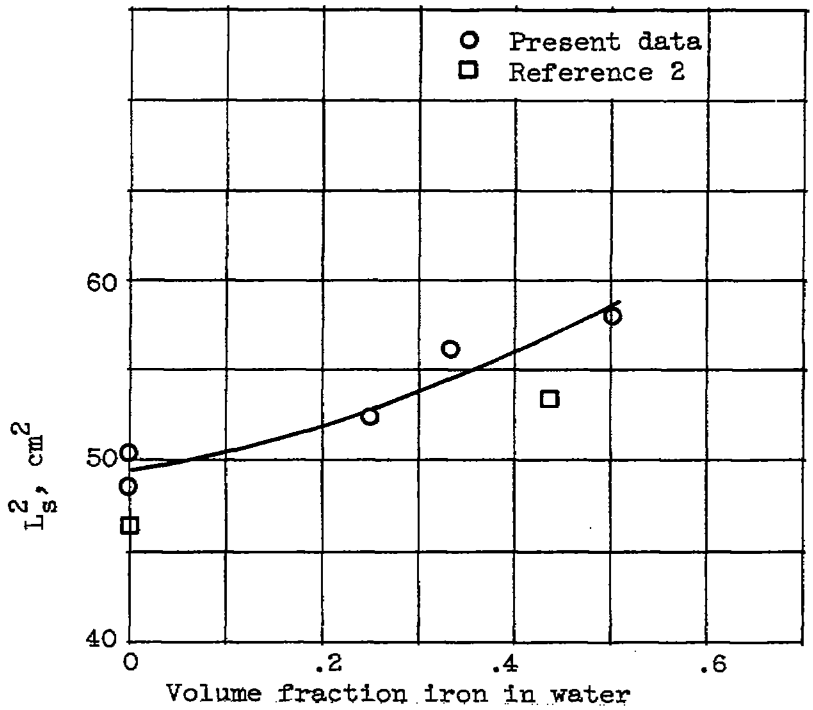

Figure 4. - Characteristic length to indium resonance of Ra-α-Be neutrons in water-iron mixtures.

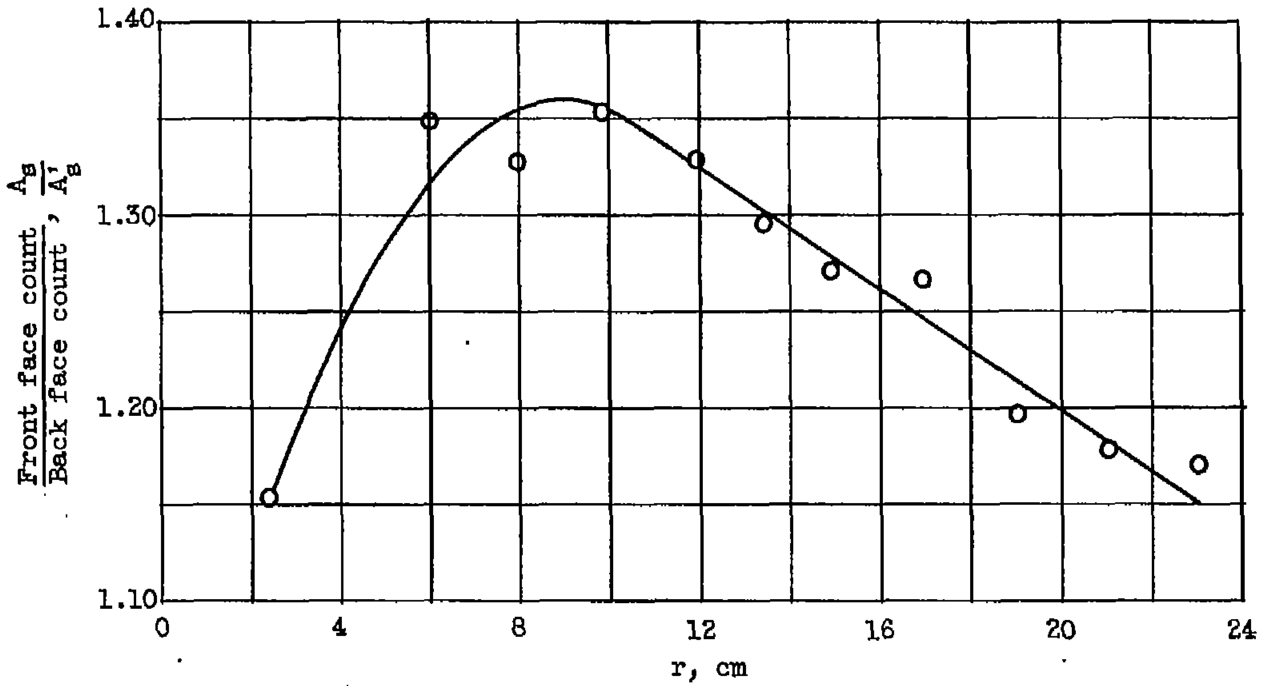

Figure 5. - Ratio of counts per minute of front face of indium foils to counts per minute of back face for water.

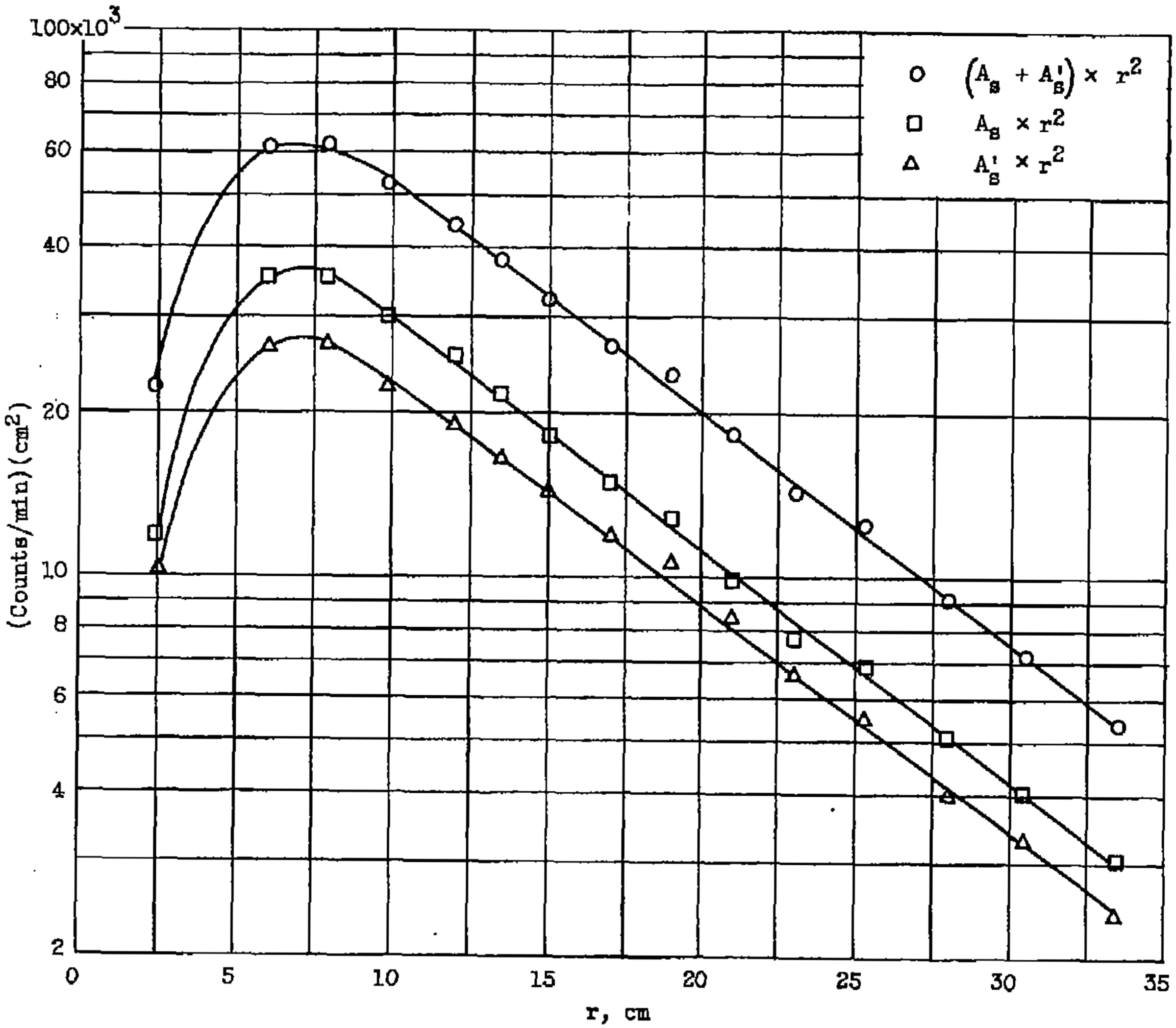

Figure 6. - Indium resonance slowing-down distributions for water using three foil counting techniques.

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